TRACE ELEMENT ANALYSIS OF ABORIGINAL GREENSTONE ARTEFACTS

To Discriminate Between the Sources, Mount Camel and Mount William in Southeastern Australia

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ABSTRACT: As rocks at the Mount William and Mount Camel Aboriginal greenstone artefact quarries in central Victoria are not readily differentiated by macroscopic and microscopic features, geochemical studies were carried out. Trace element analyses were determined for twenty samples from the quarries and seventy-one artefacts. Using this method to find distinguishing attributes between quarries we are able to determine the sources of most artefacts.

INTRODUCTION

In a study of greenstone artefacts in southeastern Australia McBryde and Watchman (1976) distinguished between rock types quarried at several locations in Victoria (for example, Howqua, Geelong, Hopkins River and Jallukar), but could not differentiate material from the Mount William and Mount Camel areas. The lithologies from these two sites are so similar that hand examination, measurements of density, petrological studies and x-ray diffraction methods cannot reveal distinguishing attributes. Rock types from the other quarries are easily distinguished from each other, and from Mount William and Mount Camel, thereby allowing allocation to sources without geochemical analyses.

A small area of the Mount William quarry contains a characteristic white-spotted amphibole hornfels, a rock type not found at Mount Camel. Artefacts composed of this lithology are therefore assigned to Mount William.

Useful petrographic attributes for source characterization in some rocks from Mount Camel are small plates of diopside, amphibole pseudomorphs, relict tuffaceous texture and carbonate and epidote veins. Otherwise there is little difference between amphibole hornfelses at Mount William and Mount Camel. As not all the artefacts examined in this study could be sourced using these petrographic features we decided to use statistical evaluations of geochemical data to characterize each quarry and then fit the artefacts to a specific source.

The method of trace element analysis was selected for discrimination purposes because it is relatively simple, less involved than major element analysis, and because similar techniques have proved successful in solving other archaeological problems: for example Cann *et al.* (1969), Ward (1974), Sigleo (1975). Preliminary trace element analyses of artefacts and quarry materials indicate that several elements could be used to discriminate between sources of amphibole hornfelses. In this paper the method of analysis, statistical evaluations and problems involved in allocating each artefact to a specific source are discussed.

PETROGRAPHY

The Mount William and Mount Camel Aboriginal artefact quarries lie along the Mount William-Heathcote-Colbinabbin Greenstone Belt (Fig.1). This belt is composed of basic metavolcanics and altered pyroclastics (Skeats 1908, Thomas & Singleton 1956).

At Mount William exploitation of outcrops and stone working activity was carried out diagonally across the Lower Unit of the Cambrian Heathcote Greenstone. The Lower Unit is almost vertical in

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the quarry area and consists essentially of amphibole hornfels (impure nephrite, Gregory 1903), up to five hundred m thick. The unit is characterized by spheroids filled with quartz, carbonate, and albite, the interlocking amphibole needles forming a decussate texture. Rocks quarried for artefacts are generally green to black and strongly recrystallised.

Two small areas near Mount Camel were worked in outcrops of the Heathcote Greenstone along strike for 200 m over a width of 30 m and on a knoll about 100 m in diameter. In the Mount Camel region metavolcanics, metadolerite and small lenses of chert comprise the Heathcote Greenstone. Rocks were quarried in metavolcanics and consist predominantly of actinolite and cummingtonite with minor amounts of albite, carbonate and epidote. They contain spheroids filled by quartz and albite, and strongly resemble similar features found in rocks at Mount William. In general the artefacts are green to brown and have decussate texture.

Rocks in the two quarry areas are petrographically similar because they share the same geological histories (Skeats 1908, Thomas & Singleton 1956). After extrusion of an extensive area of volcanics, the parent rocks of the Heathcote Greenstone, post-consolidation and metamorphic processes affected the primary minerals and textures. The metavolcanics are of Alpine-type ultramafic affinity and geochemically similar to olivine pyroxenite (Watchman 1977). At Mount William isochemical contact metamorphism took place whereas in the Mount Camel area the rocks were metasomatised.

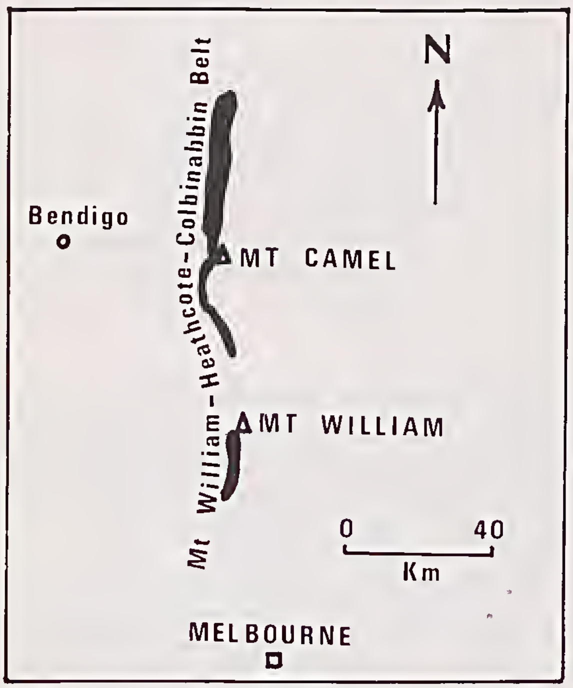

FIG. 1 — Locality map showing the positions of the Mount William and Mount Camel Aboriginal greenstone axe quarries.

GEOCHEMICAL METHODS

Rock samples from the quarry sites and slices taken out of artefacts were crushed to fine powders using a tungsten lined Seibtechnic grinding mill. The powders were then pressed into pellets for subsequent x-ray fluorescence analysis (Norrish & Chappell 1967). All analyses were carried out on a Philips PW 1220 X-ray Fluorescence Spectrometer. Rubidium (Rb), strontium (Sr), yttrium (Y) and lead (Pb) were measured with a molybdenum target x-ray tube using a scintillation counter, LiF_{200} analysing crystal and coarse collimator. Zirconium (Zr), niobium (Nb), nickel (Ni), copper (Cu) and zinc (Zn) were determined under similar conditions but with a tungsten target x-ray tube. Mass absorption coefficients were measured for each sample and corrections made for interelement effects, instrument drift, and detector dead time. Concentrations of trace elements in quarry materials are given in Table 1 and for the artefacts in Table 2.

METHODS OF DISCRIMINATION

After analysis of rocks from the quarries and artefacts, the problem was to try to fit the concentration of trace elements of each of the artefacts with the concentration of similar elements in samples of raw material from the quarries. Fig. 2 shows the ranges in trace element values for rocks from each quarry and of the population of artefacts. Binary and ternary diagrams (Figs.3-6) are used to illustrate the wide variation in several trace elements. Since all the specimens were petrographically similar and had proven indistinguishable in earlier studies, statistical tests were applied to determine differences in chemistry between quarry samples.

To find a disparity in the trace element chemistry of samples from each quarry a statistic, called the similarity coefficient, was computed for all quarry materials, using average trace element contents. This statistic was calculated according to the method of Borchardt *et al.* (1972), in which a simple equation is evaluated. At the ninety-five per cent confidence level, similarity coefficients of greater than 0.800 indicate excellent correlation between samples and when less than 0.560, a pair of samples are probably derived from different sources (Sigleo 1975). Results of this test for Mount William (d_w) and Mount Camel (d_c) are listed in Table 3.

A multivariate statistical test was devised, following Rao (1973, p.577-579), in which a linear discriminant function similar to Mahalanobis's distance was evaluated. This test is used to classify an artefact according to the statistical significance of the fit of trace element contents in each artefact compared with average concentrations of elements in quarry samples. Essentially the method is to take the means of tracc element values, calculate the covariance sums of squares matrices and evaluate a complex quadratic equation. The order of testing is to find whether a sample fits either a new population (P_{new}) or one of P_1 (Mount William) and P_2 (Mount Camel). When any test is significant at the five per cent level the sample is assigned to that population and another sample is then tested. Two additional cases may also arise and these need to be briefly mentioned.

When a sample fits both P_1 and P_2 it is evidence that the artefact is representative of a 'special' p_{new} which is between P_1 and P_2. On the other hand if both tests for P_1 and P_2 are not significant this means that there is no clear-cut solution to the classification of the sample. Results of this testing procedure using raw data and their logarithmic transformations are listed in Table 3.

DISCUSSION

It is important to realise that to obtain effective source and artefact characterization the researcher should seek for the most easily recognized property of source material which can be determined in a routine manner. It may prove costly and ineffective to strive by complex analytical and computer techniques to try to establish attributes of material from a source when a relatively inexpensive, unsophisticated and rapid method is more practical.

Following these lines our investigation into sourcing studies of greenstone artefacts began by determining the simplest characteristic feature of quarry materials and matching attributes between them and artefacts. This method relies on being able to find features in artefacts which fit the

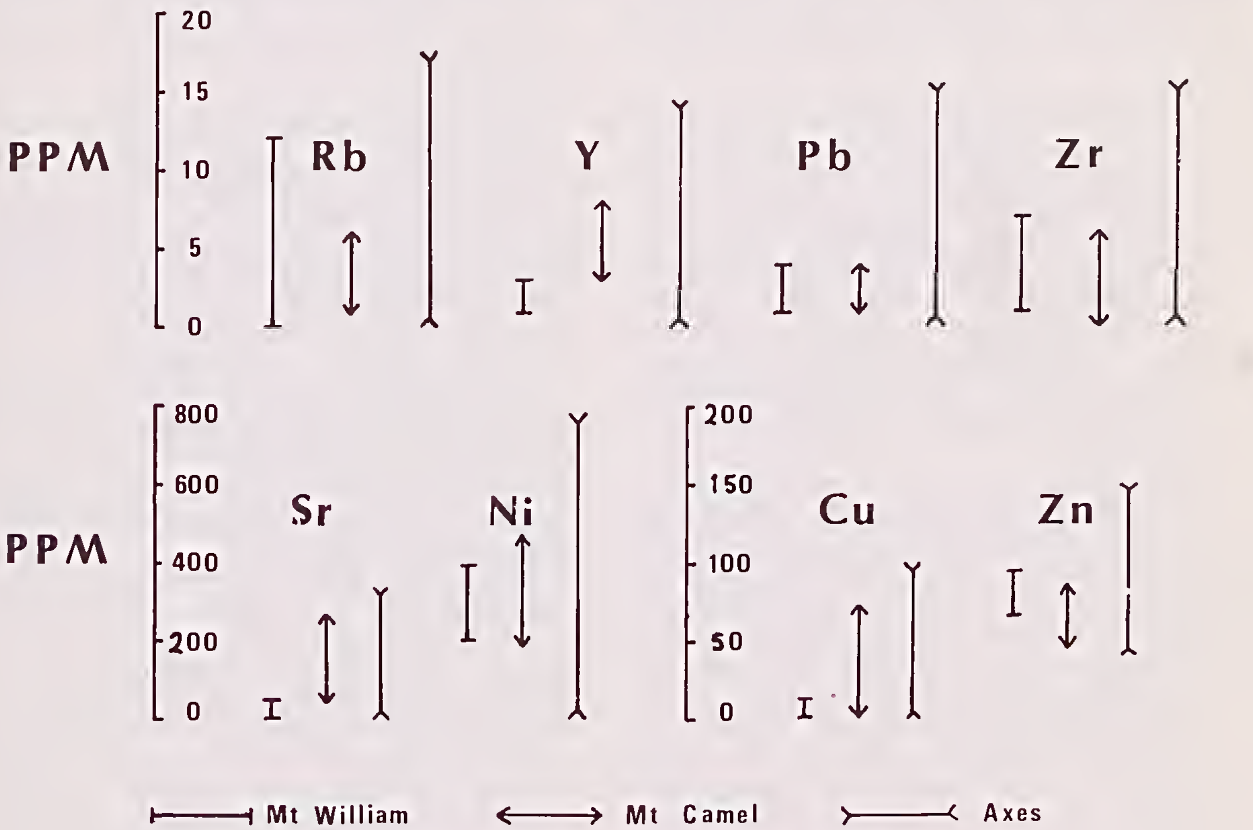

FIG. 2 — Ranges of trace element contents in quarry samples and axe-stones.

observed range of characteristic attributes of quarry samples. In some cases this is easily carried out, but in others an artefact cannot be assigned to a particular quarry. The principles involved in source characterization and allocation of artefacts to specific source areas have been discussed by De Bruin *et al.* (1976).

Artefacts from Mount William and Mount Camel have slightly different colours, textures and mineral assemblages. Pale brown axes are more likely to come from the quarry near Mount Camel whereas black artefacts are almost certainly derived from Mount William. However, the existence of a continuous spectrum from green-brown to green-black for all materials means that colour can be used only as an initial guide to the source of an artefact.

Most artefacts are fine-grained and compact, generally without features diagnostic of material from a particular quarry. The exception is the white-spotted hornfels consisting predominantly of actinolite with tiny aggregates of cummingtonite. This rock is easily recognised in hand specimen by its texture, which is similar to spotted hornfels shown by pelitic rocks in contact metamorphic terrains. This characteristic rock type is found only at Mount William; therefore artefacts composed of this lithology are certainly derived from that source.

Finding distinguishing attributes of the materials used for artefacts would not normally be expected to be as difficult as that found in the present study of amphibole hornfelses. Minor problems of source characterization have been overcome in dealing with obsidian, flint, soapstone and other lithologies using computer based statistical analyses of trace element concentrations. In this project, however, we have been unable to obtain for every specimen attributes which would clearly distinguish amphibole hornfelses of Mount William from those of Mount Camel.

Trace element analyses of seventy-one artefacts out of a total number of fifteen hundred have given us preliminary information from which tentative source allocations can be made. There is a strong possibility that major element values can be used to differentiate between these two sources, but considerable time and expense will be needed to verify this conclusion.

Concentrations of Rb, Pb, Zr, Ni, Cu and Zn in amphibole hornfelses from the two quarries are similar (Fig.2). On the other hand, values for y and Sr do not overlap and therefore these elements are possible discriminants. The range of trace element concentrations in the population of artefacts, when compared with the spread shown by quarry samples, leads to two possible explanations.

The wider range of values in artefacts may result either from poorly representative quarry samples or because petrographically comparable material is available from another (as yet unknown) source. Both possibilities together may contribute to the observed ranges for Y and Sr in the artefact population. Under these circumstances the allocation of artefacts to sources based on Y and Sr must be treated with reservation.

Discrimination between sources is illustrated in Figs. 3-6. Covariance relations between Y and both Sr and Zr enable classification of most artefacts because there are significant differences between these elements for samples from the quarries. Y is apparently the most effective discriminant, being present in Mount William artefacts below three parts per million and in greater amounts in Mount Camel samples.

Ternary diagrams (Figs. 5, 6) also illustrate differences and similarities between samples from the two quarries. Even though quarry materials are easily separated from each other the addition of components which are not good discriminants themselves leads to a decrease in the effectiveness of source characterization. Consequently Y is the best single discriminant of all the elements determined.

Results of the two statistical methods do not promise any more than can be obtained by using Y. The application of multivariate analysis to geochemical data obtained from archaeological specimens has been useful in classifying sources of artefacts; for example Hodson (1969), Ward (1974) and Bieber *et al.* (1976). So then why does the multivariate approach fail in this case?

Multivariate analysis of geochemical data to characterize different sources is based on several assumptions. Each source is thought of as being geochemically homogeneous with normally distributed trace element values. Different sources are considered to have clearly separate ranges in their trace element concentrations.

The statistical methods do not decisively identify the distinguishing attributes in rocks from each source because of the inhomogeneity of the formations quarried. Multivariate analysis is not applicable in this case to classify sources of artefacts because of the geochemical similarity of source materials (that is, the ranges of values overlap), trace element concentrations in quarry samples are skewed and not normally distributed, the geochemistry of the artefact population is not bimodal, and unknown sources may contain petro-

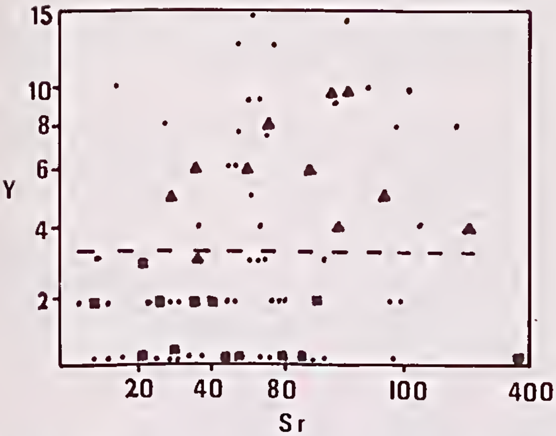

FIG. 3 — Plot of Y against Sr for Mount William (squares), Mount Camel (triangles) quarry materials and axe-stones (circles).

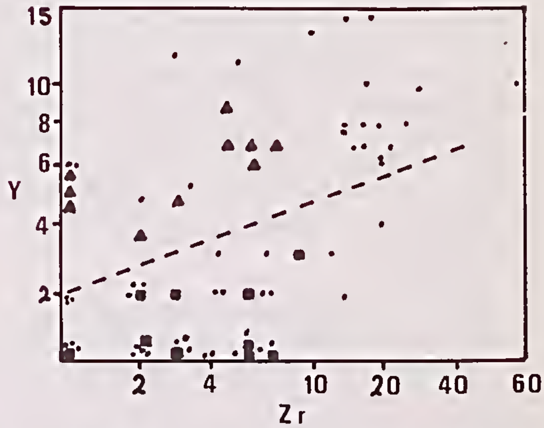

FIG. 4 — Plot of Y versus Zr for quarry materials and axe-stones (same symbols as Fig. 3).

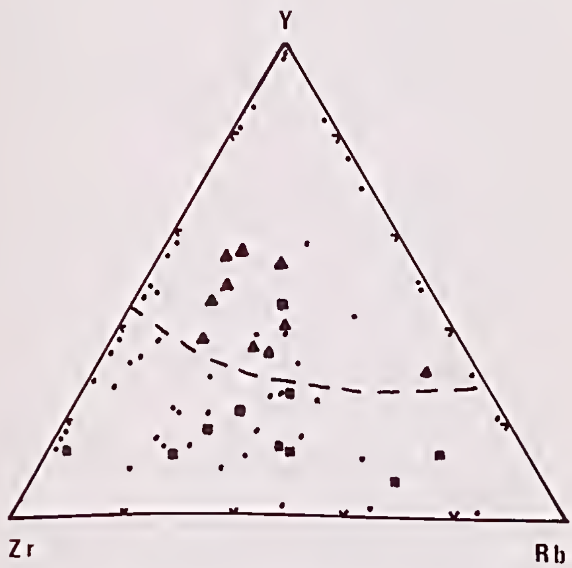

FIG. 5 — Relation between Y-Zr-Rb for quarry samples and axe-stones (same symbols as Fig. 3).

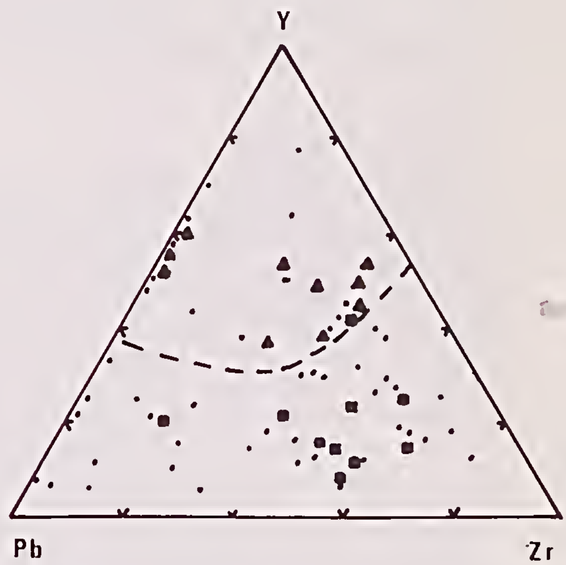

FIG. 6 — Relation between Y-Pb-Zr for quarry samples and axe-stones (same symbols as Fig. 3).

graphically and geochemically comparable material which have not been taken into consideration.

Amphibole hornfelses at Mount William and Mount Camel contain different amounts of Al_2O_3, Fe_2O_3, MgO, CaO, Na_2O and P_2O_5 (Table 1). These are possible attributes suitable for source and artefact characterization. We have not analysed artefacts for major elements because the x-ray fluorescence technique available to us is not a rapid, cheap routine method. Another simpler method, preferably non-destructive, such as non-dispersive x-ray fluorescence, is needed to analyse the large number of artefacts in collections.

CONCLUSION

This study has shown that source discrimination of Aboriginal artefacts from the Mount William and Mount Camel quarries is not always effective using trace element analysis alone. However, it is possible using selected trace elements (Y,Sr,Zr), combined with megascopic and microscopic features to characterize the quarry materials and thereby allocate artefacts to a specific quarry. It should be emphasised that when sourcing artefacts from sites with similar geological histories it is essential to understand and appreciate the geological processes which have affected the rocks. From our study we are able to determine the sources of most of the artefacts analysed for trace elements.

ACKNOWLEDGMENTS

Mr. A. West and Mrs. A. Oates of the National Museum of Victoria, Melbourne, provided thin slices from artefacts and assisted in the field. Other samples were obtained from the National Ethnographic Collection, Canberra. All analytical work was carried out at the Department of Geology, Australian National University and Dr. B. Chappell helped with x-ray fluorescence analyses. A computer program for the statistical test was devised by Dr. D. Chant of the Statistics Department, A.N.U. Mrs. B. Sanders kindly read and criticised an early draft of this paper.

This project is part of a detailed investigation of the sources, distributions and typology of Aboriginal greenstone artefacts in southeastern Australia, which is funded by an A.R.G.C. grant to Dr. I. McBryde of the Department of Anthropology, Australian National University.

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TABLE 1

SELECTED MAJOR AND TRACE ELEMENT ANALYSES OF AMPHIBOLE HORNFELSES FROM QUARRIES AT MOUNT WILLIAM AND MOUNT CAMEL

	Mount William			Mount Camel		
SiO_2	54.47	55.84	51.20	50.08	50.12	50.78
TiO_2	.03	.03	.01	.12	.22	.20
Al_2O_3	3.26	3.08	1.29	5.83	9.28	8.99
Fe_2O_3	5.20	3.04	6.13	2.17	2.14	1.74
FeO	7.25	8.73	4.85	5.47	6.61	6.83
MnO	.18	.17	.24	.24	.18	.17
MgO	22.85	23.75	24.12	11.06	14.37	13.83
CaO	3.92	2.29	5.80	22.05	14.54	14.99
Na_2O	.19	.20	.22	.35	.59	.51
K_2O	.07	.02	.01	.26	.07	.05
P_2O_5	.01	.01	.01	.07	.03	.04
S	–	–	–	.01	.01	.01
H_2O+	2.39	2.42	3.67	1.09	1.77	1.82
H_2O-	.05	.07	.08	.07	.05	.07
CO_2	.05	.04	1.65	1.07	.09	.08
TOTAL	99.92	99.69	99 28	99.93	100.07	100.10
Rb	5	2	1	1	2	2
Sr	348	52	72	37	46	25
Y	7	6	6	6	1	7
Pb	5	5	5	3	3	3
Zr	29	14	18	27	11	10
Nb	–	–	1	–	–	–
Ni	522	272	398	479	491	395
Cu	2	45	4	3	3	6
Zn	114	93	82	109	91	92

TABLE 2

TRACE ELEMENT CONTENTS IN AMPHIBOLE HORNFELS ARTEFACTS

Axe No.	Rb	Sr	Y	Pb	Zr	Nb	Ni	Cu	Zn
162	1	58	8	2	10	1	698	24	77
163	0	101	1	10	0	0	292	6	186
166	0	74	2	10	4	0	245	3	83
170	0	30	7	6	9	0	1000	31	76
187	1	17	2	2	6	1	257	4	103
190	1	47	7	6	10	0	748	27	82
196	1	36	1	3	2	0	344	3	79
198	3	37	1	3	5	0	262	30	95
205	0	17	1	3	2	0	319	8	81
209	2	188	2	1	0	0	352	5	82
221	1	29	1	3	3	0	304	3	71
225	2	55	2	5	1	0	384	15	72
227	0	244	3	3	0	0	260	3	62
258	3	73	2	4	2	0	220	37	83
264	0	43	6	6	1	0	84	59	69
270	0	75	12	1	3	0	80	83	70
279	2	24	2	5	6	0	278	63	81
280	1	65	8	5	12	0	682	33	81
281	0	14	1	15	2	0	546	16	51
297	2	15	1	3	2	0	346	4	83
303	16	55	16	15	20	1	117	98	108
327	0	55	5	3	3	0	227	19	77
331	1	63	7	3	15	2	244	11	89
338	2	14	3	6	6	1	199	5	89
343	0	295	7	4	0	0	200	5	76
346	0	114	8	6	8	1	688	3	70
351	0	38	1	3	1	0	263	8	78
359	1	44	2	5	1	0	399	3	67
363	0	109	3	36	2	1	222	13	77
398	8	93	13	6	11	1	97	75	80
409	1	29	1	2	2	0	471	4	75
411	8	199	7	3	0	1	731	28	65
412	0	99	2	1	11	0	409	9	58
419	2	79	1	7	0	0	345	10	81
424	3	32	2	1	2	0	393	5	81
435	0	51	12	3	5	0	64	47	77

TABLE 2 (Continued)

TRACE ELEMENT CONTENTS IN AMPHIBOLE HORNFELS ARTEFACTS

Axe No.	Rb	Sr	Y	Pb	Zr	Nb	Ni	Cu	Zn
474	1	38	1	4	0	0	412	3	62
479	2	65	1	6	1	0	309	4	74
484	1	128	16	10	15	1	146	18	64
485	0	59	1	7	4	0	265	3	156
542	2	66	3	3	10	0	270	31	71
544	0	66	4	2	15	1	376	7	59
547	0	42	6	6	1	0	97	93	64
552	3	69	3	10	4	0	366	2	86
560	6	65	1	6	2	0	365	9	95
572	4	44	2	8	2	0	340	27	73
575	0	20	2	4	3	0	313	1	67
576	7	90	13	3	19	1	75	110	57
577	2	106	13	40	12	1	139	57	109
579	4	148	1	4	0	0	281	25	69
588	1	51	2	2	0	0	368	7	69
589	0	37	2	2	1	0	399	4	70
590	1	204	2	4	2	0	267	186	53
592	2	17	1	3	3	1	404	1	73
602	1	72	3	2	0	1	236	38	40
605	0	79	1	3	0	0	313	15	64
607	1	36	0	2	1	0	304	2	67
608	0	78	2	2	0	0	288	2	64
609	0	112	1	2	0	0	314	4	75
610	1	59	1	8	1	0	261	7	68
611	6	35	0	1	1	0	434	1	71
615	2	187	1	4	0	0	291	7	63
623	0	12	2	1	2	0	363	14	56
624	0	47	1	3	5	0	288	2	67
625	4	105	8	4	16	1	242	127	96
627	1	23	1	4	6	1	232	2	80
628	2	207	10	8	0	1	155	3	81
629	4	27	0	2	2	0	436	1	68
630	0	27	1	1	4	0	309	7	71
634	4	143	10	4	19	1	236	6	99
643	3	30	2	3	4	0	310	5	75

TABLE 3

SUMMARY OF RESULTS OF THE SOURCE DISCRIMINATION METHODS:

Axe No.	Hand examn. & petrology	From Figs. 2, 3, 4.	Similarity co-efficients		Statistical tests		Final
			d_W	d_C	raw	log	
MW162	W/C	C	.428	.617	new	new	C
163	"	W	.510	.371	"	"	W
166	"	W	.537	.503	"	"	W
170	C	C	.447	.469	"	"	C
187	W/C	W	.587	.491	"	"	W
190	"	C	.455	.569	"	"	C
196	"	W	.740	.582	W	W	W
198	W	W	.753	.642	W	W	W
205	W/C	W	.707	.529	W	W	W
209	"	W	.526	.518	new	new	W
221	"	W	.811	.637	W	W	W
225	"	W	.617	.725	W	W	W
227	"	W	.420	.484	new	C	C
258	"	W	.675	.674	"	W-C	W-C
264	"	C	.388	.469	"	new	C
270	W/C	C	.369	.508	"	"	C
279	"	W	.659	.603	"	W	W
280	"	C	.443	.578	"	new	C
281	"	W	.500	.414	"	"	W
297	"	W	.759	.615	W	W	W
303	"	C	.296	.327	new	new	C
327	C	C	.567	.766	C	C	C
331	C	C	.515	.648	new	new	C
338	W/C	W	.628	.549	"	"	W
343	"	C	.464	.441	"	"	C
346	C	C	.407	.479	"	"	C
351	W/C	W	.684	.506	W	W	W
359	"	W	.592	.531	W	W	W
363	"	W	.445	.547	new	new	W-C
398	"	C	.385	.474	"	"	C
409	"	W	.721	.479	W	W	W
411	"	C	.359	.570	new	new	C
412	W	W	.436	.495	"	"	W-C
419	"	W	.630	.590	"	"	W
424	"	W	.736	.535	"	"	W
435	W/C	C	.416	.514	"	"	C

NOTE:

d_W, d_C: similarity coefficients of axes compared to average trace element values of Mount William and Mount Camel respectively. W — Mount William, C — Mount Camel, W/C Mount William/Mount Camel undifferentiated.

TABLE 3 (Continued)

SUMMARY OF RESULTS OF THE SOURCE DISCRIMINATION METHODS:

Axe No.	Hand examn. & petrology	From Figs. 2, 3, 4.	Similarity co-efficients d_w	d_c	Statistical tests raw	log	Final
474	W/C	W	.640	.462	W	W	W
479	W	W	.713	.607	W	W	W
484	W/C	C	.358	.536	"	"	C
485	"	W	.587	.434	"	"	W
542	"	C	.561	.767	"	"	C
544	C	C	.475	.556	"	"	C
547	W/C	C	.381	.454	"	"	C
552	"	W	.621	.598	"	"	W
569	W	W	.595	.490	W	W	W
572	W	W	.666	.560	new	new	W
575	W/C	W	.575	.490	W	W	W
576	"	C	.350	.456	new	new	C
577	W	C	.300	.442		"	C
579	W/C	W	.473	.530	"	"	W-C
588	"	W	.558	.536	W	W	W
589	"	W	.555	.468	W	W	W
590	"	W	.530	.565	new	new	C
592	"	W	.731	.641	"	"	W
602	"	C	.378	.561	"	"	C
605	W/C	W	.537	.593	W	W--C	W-C
607	"	"	.519	.498	"	W	W
608	"	"	.435	.490	"	W-C	W-C
609	"	"	.543	.467	"	W	W
610	"	"	.657	.529	new	new	W
611	"	"	.460	.387	W	W	W
615	"	"	.682	.580	new	W-C	W-C
623	"	"	.476	.486	W	new	W
624	"	"	.640	.544	"	W	W
625	"	C	.500	.569	new	new	C
627	"	W	.713	.486	"	"	W
628	"	C	.423	.472	"	"	C
629	"	W	.572	.485	W	W	W
630	"	"	.709	.483	"	"	W
634	"	C	.598	.532	"	new	W-C
643	"	W	.842	.661	new	"	W